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Effectiveness of Form Liners in Improving Concrete Durability

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Abstract	The results of a field study to evaluate the effectiveness of form liners in improving the durability and extending the service life of concrete are analyzed, discussed, and summarized in this report. The bridge barrier walls of forty six structures constructed under MTO contracts between 1992 and 2004, using five different form liners, were evaluated visually and tested non-destructively. Three surface conditions - surface voids, discoloration, and scaling, the most frequently observed indicators of durability of the surfaces formed with the liner were rated using a 5-point system. Properties of the concrete surface layer including hardness, air permeability, electrical resistivity and moisture content were tested non-destructively on adjacent wall surfaces formed with and without use of a liner. Based on the results of visual evaluation and non-destructive testing, it was concluded that there was no evidence of the improvement in the long-term concrete durability significant enough to justify specification of the use of form liners as a concrete durability enhancement method.
Key Words	Form liners, formwork, concrete durability, surface defects, non-destructive testing
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Table of Contents

Executive Summary iv

1. INTRODUCTION 6
1.1 Scope of the study 6

2.FORM LINERS 8
2.1 Interaction between form liner and concrete 8
2.2 Types of form liner 8
2.3 Manufacturer's specifications 8
2.3.1 Installation 9
2.3.2 Concrete placement 9
2.3.3 Re-use and disposal 10

3. VISUAL EVALUATION OF LONG-TERM PERFORMANCE OF CONCRETE FORMED WITH LINER 11
3.1 Evaluation criteria 11
3.2 Rated surface conditions 11
3.3 Rating system and visual standards for surface conditions 12
3.4 Non-rated surface conditions 13
3.5 Analysis and summary of visual evaluation 13
3.5.1 Long-term performance of concrete formed with liner 14
3.5.2 Long-term performance of concrete formed without liner 15
3.5.3 Long-term performance of concrete surface formed with and without liner 16

4. NON-DESTRUCTIVE TESTING OF SURFACES FORMED USING LINERS. 18
4.1 Testing of the quality of concrete surface formed using liners – REview of Literature 18
4.2 Field testing of the effectiveness of form liners 18
4.2.1 Evaluation criteria and test sites 18
4.2.2 Non-destructive tests 19
4.2.3 Test results and analysis 20

5. SUMMARY AND CONCLUSIONS 22

6. REFERENCES 23

List of Tables

Tab.1 MTO Nortwestern Region sites
Tab.2 MTO Northeastern Region sites
Tab.3 MTO Southwestern Region sites
Tab.4 MTO Eastern Region sites
Tab.5 MTO Central Region sites
Tab.6 Visual evaluation of surface condition, surfaces formed with liner
Tab.7 Visual evaluation of surface condition, surfaces formed without liner
Tab.8 Non-destructive testing of surfaces formed with and without liner

List of Figures

Fig. 1 Form liners used in 1992-2004 MTO Contracts
Fig. 2 Imprint of form liner L1
Fig. 3 Imprint of form liner L2
Fig. 4 Imprint of form liner L3
Fig. 5 Imprint of form liner L4
Fig. 6 Imprint of form liner L5
Fig. 7 Open voids, visual rating 1 point (light)
Fig. 8 Open voids, visual rating 2 points (mild)
Fig. 9 Open voids, visual rating 3 points (moderate)
Fig.10 Open voids, visual rating 4 points (severe)
Fig.11 Open voids, visual rating 5 points (very severe)
Fig.12 Discoloration, visual rating 1 point (light)
Fig.13 Discoloration, visual rating 2 points (mild)
Fig.14 Discoloration, visual rating 3 points (moderate)
Fig.15 Discoloration, visual rating 4 points (severe)
Fig.16 Discoloration, visual rating 5 points (very severe)
Fig.17 Scaling, visual rating 1 point (light)
Fig.18 Scaling, visual rating 2 points (mild)
Fig.19 Scaling, visual rating 3 points (moderate)
Fig.20 Scaling, visual rating 4 points (severe)
Fig.21 Scaling, visual rating 5 points (very severe)
Fig.22 Non-rated condition, crazing
Fig.23 Non-rated condition, wrinkles/liner folds (A)
Fig.24 Non-rated condition, wrinkles/liner folds (B)
Fig.25 Non-rated condition, subsurface voids (exposed by grinding)
Fig.26 Rebound hammer test
Fig.27 TORRENT air permeability test – surface formed with liner
Fig.28 TORRENT air permeability test – surface formed without liner

Fig.29 Wenner resistivity test
Fig.30 Moisture content test using capacitance probe

Executive Summary

The report presents the results of a ministry field study carried out to evaluate the effectiveness of textile form liners in improving the long term durability and extending the service life of concrete.

The concept of absorptive formwork to improve the surface quality of concrete was introduced in the 1930's, and in the 1980's the availability of permeable textile form liners (woven or non-woven textiles acting as a filter) attracted the interest of the ministry. The form liners were intended to filter out the water and allow the air accumulated at the concrete-formwork interface to escape, thus decreasing the water-to-cement ratio and porosity of the near-surface zone of concrete, and improve its durability.

The first MTO application of form liner for bridge barrier wall took place in 1992; the liners were evaluated on trial contracts in each of five MTO Regions, typically two installations per Region. Based on the results of the trial installations, it was concluded that there was not any significant improvement of the overall quality or short-term durability of the concrete barriers construction with form liners. Their use was not endorsed and did not become part of the ministry's standard practice, however a number of additional walls were constructed with the liners, with one Region using the liners on a routine basis because of what they considered to be a marked improvement in concrete scaling resistance.

Based on concern with the inconsistent approach displayed by the Regions, Concrete Section was asked by Bridge Committee to carry out a definitive study on the effectiveness of the liners in improving the long-term durability of the concrete in the bridge barriers.

In this study, the barrier walls of forty six structures constructed under MTO Contracts between 1992 and 2004 were evaluated visually and tested non-destructively.
The special provisions for the use of form liners on a trial basis specified use of the liner on the inside faces of the panels with the exception of the panels at each end, which were to be formed in a conventional manner, without the liner. Thus, the end panels could be used as control in field evaluation. After the initial trials were complete, liners were sometimes specified for the entire internal surface of the barrier walls; where there were no structures with partial liner application, comparable structures with barrier walls cast without liner were located and inspected.

Five different form liners were used in the selected 1992-2004 MTO Contracts. Three surface condition - surface voids, discoloration, and scaling, the most frequently observed indicators of durability of the surfaces formed with the liner, were rated using a 5-point system. Other non-rated surface conditions, occurring sporadically, and having lesser

effect on concrete durability, such as crazing, subsurface voids, wrinkles (liner folds) were also discussed.

The properties of the concrete surface layer including hardness, air permeability, electrical resistivity and moisture content were tested non-destructively on side-by-side surfaces formed with and without use of the liner.

Based on visual evaluation, acceptable performance was evaluated for 30 percent of all barrier walls formed with the liner versus 21 percent of formed without the liner. Unacceptable performance was confirmed for 70 percent of barrier walls formed with the liner versus 79 percent of formed without the liner. The changes in hardness, air permeability, electrical resistivity and moisture content as the indicators of the quality of surfaces formed with liner were negligible.

It was concluded that there is no evidence of an improvement in the long-term concrete durability that is significant enough to justify specification of the use of form liners for enhancement of concrete durability.

1. Introduction

During the concrete placement, the vibration process forces water and air in the concrete mix towards the concrete-formwork interface. Consequently, the concrete mix properties at the surface are different than those away from the surface – at the surface the water/cement ratio and air content increase, while the cement content decreases. The quality of approximately 10 to 20 mm surface zone of concrete is affected by those changes.

To improve the quality of the surface zone, a concept of absorptive formwork (boards made of a pressed absorptive material) was introduced in 1930's, then, in 1980's, permeable formwork liners (woven or non-woven textiles acting as a filter) gained increasing interest.

There are many literature sources reporting the results of laboratory, or short term field performance investigations to determine the effectiveness of form liners in improving the quality of the concrete surface [1, 2, 3, 4]; some of them commissioned by the manufacturers of form liners [5, 6, 7, 8]. So far, there are no reports of the long-term (10 years or beyond) studies resulting in a conclusive evaluation of the benefits of form liner use.

The first MTO application of form liner for a placement of bridge barrier wall took place in 1992. Since then, many bridge barrier walls have been cast with the use of form liners in all five Regions of the MTO. Two internal reports on field performance of form liners in the MTO Northeastern (former Northern) Region have been prepared by the regional QA staff [9, 10].

In this report, the results of a field study to evaluate the effectiveness of form liners in improving the durability and extending the service life of concrete are analyzed, discussed and summarized.

Many different names, such as permeable formwork, controlled permeability formwork, textile form liners, etc., have been used for this technology. The term 'form liner', or 'liner' will be used throughout this report.

1.1 SCOPE OF THE STUDY

The study consists of two parts:

- visual evaluation of the concrete surface of bridge barrier /parapet walls formed with form liner, and
- comparative, non-destructive field testing of the surfaces formed with and without liner carried out for selected structures.

During the 2005 summer and fall investigation carried out in five regional jurisdictions of the MTO, an initial inventory of 1992 - 1994 MTO Contracts with 16 structures expanded to 46, as many more structures with form liners, constructed after 1994, were located.

Visual inspections of 46 bridge structures with the barrier walls cast with or without form liners were carried out. Some of the barrier walls cast with the form liner had their wingwall (end) panels formed without the liner to provide a control surface for evaluation. In some MTO Regions, where there were no structures with partial liner application, comparable structures with barrier walls cast without liner were located and inspected.

Tables 1 to 5 contain the information about inspected barrier walls.

The scope of this study covers the evaluation of:

- Structures with form liners in Nortwestern, Northeastern, Soutwestern, Eastern and Central Region, constructed between 1992 and 2003. The quantities of barrier walls cast with liners shown in Tables 1-5 are representative of the extent and timing of liners'use, i.e. Northwestern - eight barrier walls (1992-1997) Northeastern- seventeen (1992-2003), Southwestern - six (1992-1994), Eastern – four (1992-1993), Central Region-two barrier walls(1992).
- Five types of form liner: L1, L2, L3, L4, L5
- Two types of concrete: conventional (30 MPa) and high performance concrete (HPC) (50MPa).

In summer and fall of 2006, non-destructive testing to evaluate selected properties of concrete surfaces cast with form liner, as compared to those cast without the liner was carried out.
Testing included:

- Hardness using rebound hammer
- Air permeability, using Torrent Air Permeability Tester
- Electrical resistivity, using a four-point Wenner probe
- Moisture in near-surface concrete, using electrical capacitance probe.

2. FORM LINERS

2.1 INTERACTION BETWEEN FORM LINER AND CONCRETE

Studies to determine the interaction between the form liner and plastic concrete showed that while casting concrete against a plywood or steel surface increased the initial w/c ratio by 20% and the concrete porosity by 15% in the 20 mm deep surface zone, the use of form liners decreased the initial w/c ratio by 25% and the porosity of concrete by 25% [11].

The form liner filters out the water and allows the air accumulated at the concrete-formwork interface to escape. A certain amount of cementitious particles is removed with the water; the permeability to fine particles depends on individual characteristics of the liner. A mechanism of interaction between different types of liner and the plastic concrete is described in [12].

2.2 TYPES OF FORM LINER

Five different woven and non-woven form liners were used in the selected 1992-2004 MTO Contracts.

Woven liners are made of polyamide, polyester or polipropylene fibers, which can resist degradation in contact with a highly alkaline concrete. A woven liner can be manufactured as single (plain cloth) or double-woven (two cloths woven at once, combined by interlacing).

Non-woven fabrics are made of thermobonded polyethylene or polypropylene fibers. Some non-woven fabrics have a backing grid made of polyethylene. Non-woven fabrics made of bonded fibers are stiffer than woven fabrics, and therefore are supposed to be more resistant to sagging and wrinkling.

Fig.1 shows samples of form liners used in MTO Contracts.

L1 and L2 are non-woven liners; L2 is a second generation of liner L1 and has a backing of polyethylene grid. Liners L3, L4 and L5 are woven fabrics; the first and second are single-woven, the third is double-woven. Liner L5 requires the use of perforated formwork.

Figures 2 throughout 6 show the imprints of the liners on concrete surface.

2.3 LINER MANUFACTURERS' SPECIFICATIONS

Each type of form liner has its own specific properties, therefore liner installation and concrete placement and curing require strict adherence to manufacturers' specifications.

To illustrate specific issues related to the use of form liners, selected manufacturer's instructions are quoted below.

2.3.1 Installation

- Liner shall be manually stretched and stapled to wood forms or glued with an approved spray adhesive. It can be overlapped or butted. No release agents shall be used on formwork surface. The liner is not affected by temperature change or exposure to sunlight.

- Tensioning of liner is very important, exposing to sun during hot weather prior to tensioning is recommended. When exposed to sun for 20 min, a permanent extension of 0.15% will result. Recommended elongation during tensioning is 6mm/m lengthwise and 4mm/m across.

- Sheets shall be cut to form size, fixed with double-sided tape. Fixing during warm hours recommended. Folds are possible if there is a 10° C ambient temperature increase.

2.3.2 Concrete placement

- Liner shall be completely dry before starting the concrete pour and shall be protected from wetting. Concrete shall be poured in a continuous operation, avoiding as much as possible splashes that might dry up over the liner. Any dried concrete shall be scraped off from the liner surface prior to resuming concrete pouring.

- Concrete placement shall be carried out in one continuous operation as colour differences may show up in case of delays between pours. The wetted zone left when the concrete level drops during vibration shall not be allowed to dry out. Dry patches of cement paste shall be scraped off.

- Vibration shall be light to moderate for slumps over 80mm. Over-vibration causes colour spottiness and may introduce small bugholes. Fast extraction of the vibrator near the formwork can create bugholes. Vibrator should be kept at least 5 to 10 cm from the face of formwork. Excessive vibration should be avoided. For a bughole free surface, post-vibration (30 to 60 minutes after initial compaction) of the upper 200 mm of the pour is recommended to remove remaining air and water.

- Concrete with slump of 50 mm or lower give better results.

- Concrete will generally be darker in color than normally cast concrete. To limit colour variations between pours, delays in placing successive layers should be avoided . Wetted zones should not be allowed to dry – if so, dried areas should be scraped off.

2.3.3 Re-use and disposal

- One-time use, biodegradable, or
- One-time use, chemically inert and disposable by incineration, or
- Reuse up to three times, high pressure water cleaning between the uses.

3. VISUAL EVALUATION OF LONG-TERM PERFORMANCE OF CONCRETE FORMED WITH LINER

3.1 EVALUATION CRITERIA

Three surface conditions - surface voids, discoloration, and scaling, which were the most frequently observed on surfaces formed with the use of liners are major indicators of durability issues rated using a 5-point system.

Other surface conditions, occurring sporadically, and having lesser effect on concrete durability, are also discussed, but not rated. They are: crazing, subsurface voids, wrinkles (liner folds).

3.2 RATED SURFACE CONDITIONS

Surface voids, also called bugholes, pinholes or blowholes, are small, irregular cavities resulting from entrapment of air at the surface of formed concrete during placement and consolidation.

The removal of water and air trapped at the concrete-formwork interface is the main purpose of liner use. If successful, the removal eliminates surface voids to achieve a smooth and uniform concrete surface.

A specific amount of pressure has to be exerted through the concrete and against the formwork to push the entrapped air through the liner and out of concrete surface. Therefore, while the liners are more effective at the base and the middle section of the wall, they are much less effective in removing air from the concrete placed at the top part of the formwork, where the pressure is lower than at the bottom.

The size of surface voids can range from approximately 1 to 20 mm. When present in large numbers on the concrete surface, surface voids decrease the effective thickness of the concrete cover to reinforcing steel. Water and contaminants will eventually collect in the voids, thus affecting the durability of concrete.

Discoloration can appear as colour changes in large areas of concrete; lighter coloured areas contrasting with darker areas.

Generally, as the result of densification of cement particles and reduction of water to cement ratio (w/c) at the concrete surface, form liners make the concrete surface darker than that formed without the liner. Lighter areas may be the result of poor vibration

practices - improper size, frequency and amplitude of the vibrator and/or inadequate spacing between the vibrator insertion points. If the wet concrete splashed on the liner surface dries out and is not removed before the placement of the next concrete layer, colour variations will result, as well.

The areas of lighter concrete (higher w/c) have different properties than those of darker concrete (lower w/c), i.e. lower strength, higher permeability to water and air, thus resulting in lower durability as compared with the darker concrete.

Scaling is a loss of the surface layer of cement paste exposed to freezing and thawing. Freezing and expansion of water accumulated in concrete pores dilates and ruptures the surface layer of cement paste. De-icing chemicals increase scaling potential, as their hygroscopic properties keep concrete saturated. Concentrated salts may chemically attack the concrete.

Scaling makes the interior concrete and the reinforcing steel much more vulnerable to deterioration.

3.3 RATING SYSTEM AND VISUAL STANDARDS FOR SURFACE CONDITIONS

A 5-point rating system for the extent of each surface condition was used, as follows:
1 point – light,
2 points – mild
3 points – moderate,
4 points – severe,
5 points – very severe

The visual standard for the 5-point scale used for **surface voids** is shown in Figures 7 to 11:
Figure 7 - a few shallow voids along the top edge of the barrier wall (1 point),
Figure 8 - several shallow and deeper voids along the top third of the wall's height (2 points),
Figure 9 - many shallow and deeper voids along the top half of the wall (3 points),
Figure 10 - many shallow and deeper voids extending down to the bottom sloped part of the wall, with a few voids in a bottom part (4 points),
Figure 11- a multitude of voids spread uniformly over the entire surface of the wall (5 points).

The visual standard for the 5-point scale used for **discoloration** is shown in Figures 12 to 16:
Figure 12 - none or very small discolorations along the top edge of the wall (1 point),
Figure 13 - a strip of light-coloured concrete along the top edge of the wall (2 points),
Figure 14 - patches of a light-coloured concrete covering up to approximately 20% of the wall surface area (3 points),

Figure 15 - patches of a light-coloured concrete covering up to approximately 40% of the wall area (4 points),
Figure 16 - patches of a light-coloured concrete covering more than approximately 40% of the wall surface area (5 points).

The visual standard for the 5-point scale used for **scaling** is shown in Figures 17 to 21:
Figure 17 - small isolated areas with shallow 'dot-type' scaling (1 point),
Figure 18 - larger areas with shallow 'dot-type' scaling, a few small and shallow 'patch-type' areas (2 points),
Figure 19 - most of the wall surface covered with shallow scaling (3 points),
Figure 20 - large areas of 'patch-type' shallow scaling, small areas of deep scaling with coarse aggregate exposed (4 points),
Figure 21 - large areas of deep scaling (5 points).

3.4 NON-RATED SURFACE CONDITIONS

Crazing is the result of differential shrinkage in the surface and subsurface layers of concrete.

Since the surface cast against the liner has a higher cement and lower water content than the concrete underneath, differential tensile stresses due to shrinkage are resulting in quasi-octagonal network of shallow cracks.

Generally, shallow crazing is not considered a surface condition that will seriously compromise concrete durability. However, deeper crazing combined with other defects, such as voids or scaling may contribute to a faster onset of concrete deterioration. Example of crazing is shown in Figure 22 .

Liner folds (wrinkles) - improper installation of liner, or storage of liner-covered formwork may cause surface defects resembling wrinkles.

Figure 23 shows horizontal wrinkles caused by lack of tension in woven liner - L4, and Figure 24 - wrinkles caused by lack of tension in non-woven liner – L1. Generally, wrinkling is more of an aesthetic problem than durability related condition, but it may affect the durability through the reduction of concrete cover in localized areas.

Sub-surface voids – the use of form liner may cause a superficial closing of the concrete surface over sub-surface voids. Figure 25 shows sub-surface voids.

3.5 ANALYSIS AND SUMMARY OF VISUAL EVALUATION

Due to their different environmental conditions, as well as regional issues with concrete materials (aggregate quality) and concrete mix supply (individual supplier's performance or long delivery distances, or both) evaluated structures are grouped by MTO Region.

For the purpose of the analysis and evaluation, liner and concrete types are the primary variables.

Out of 46 structures, 21 had the barrier walls formed with L1 (full or partial coverage), 8 with L2 (full or partial coverage), 4 with L3 (full coverage), 3 with L4 (full coverage), and 1 with L5 (partial coverage). Nine structures without liner were evaluated as controls.

Out of total 46 structures evaluated, 36 were 30 MPa and 10 were 50 MPa concrete structures.

The age of concrete is a secondary variable. In all MTO Regions, the majority of 30 MPa structures evaluated in this study are 8 to 12 years old, and, in the Northeastern Region, the 50 MPa structures are 4 to 5 years old.

In Table 6, barrier wall surfaces formed using the liner (full or partial coverage) are sorted by liner and concrete type.

In Table 7, barrier wall surfaces formed without the liner are sorted by concrete type.

Long-term concrete surface performance, as a sum of points for three rated surface conditions, is interpreted as follows:
3 points - good
4 points - satisfactory
5 and 6 points - unsatisfactory
7 and more points – poor

3.5.1 Long-term performance of concrete formed with liner

From the data in Table 6, the following is the analysis of structures with liner-formed surfaces, grouped by Region:

Nortwestern Region: Eight 30 MPa structures were evaluated; five of them had barrier walls formed with L1, and three with L3.
Out of eight structures, only two, formed with L3, showed good surface performance. The remaining six structures had either unsatisfactory or poor performance.

Northeastern Region: Seventeen (seven 30 MPa, and ten 50 MPa concrete) structures with liner were evaluated. Out of seven 30 MPa barrier walls, five were formed with L1, one with L2, one with L3. Out of ten 50 MPa barrier walls, one was formed with L1, seven with L2, two with L4.
Seven out of ten 50 MPa concrete barrier walls, formed with three different liners had good or satisfactory performance. One 30 MPa wall had satisfactory performance. The remaining 30 or 50 MPa structures, formed with different liners had unsatisfactory or poor performance.
It has to be noted that at the time of visual evaluation, the age of the 50 MPa structures

was about half of the age of 30 MPa structures (approximately 5 versus 10 years of age).

Southwestern Region: Six structures evaluated, all 30 MPa concrete and all barrier walls formed with L1.
None of the structure barrier walls had good or satisfactory performance .

Eastern Region: Four structures evaluated, all 30 MPa, three formed with L1, one with L3.
None of the structure barrier walls had good or satisfactory performance .

Central Region: Two 30 MPa structures evaluated, one with barrier wall formed with L1, the other with L5.
The barrier wall formed with L5 had good performance, the other one had poor performance.

For all evaluated barrier wall surfaces formed with the liner, certain trends emerge; for instance, better performance of surfaces formed with woven liners (L3 and L4), or better performance of the high performance concrete surfaces formed with the liner. However, with the concrete age factor taken into account (in both cases the age of concrete is somewhat different then for the other structures), the non-destructive testing of the surfaces with liner versus surfaces without liner may be the only viable way to confirm if such trends really exist.

3.5.2 Long-term performance of concrete formed without liner

From data in Table 7, the following is the analysis of surfaces formed without liner:

Nortwestern Region: Two 30 MPa structures were evaluated, both have poor surface quality.

Northeastern Region: Seven (four 30 MPa, and three 50 MPa concrete) barrier wall surfaces without liner were evaluated.
Out of four 30 MPa surfaces, one has good, one satisfactory and two have poor performance. Out of three 50 MPa surfaces one has good, and two have unsatisfactory performance.
It has to be noted that at the time of visual evaluation, the age of the 50 MPa structures was about half of the age of 30 MPa structures (approximately 5 versus 10 years of age).

Southwestern Region: Eight barrier wall surfaces formed without liner evaluated, all 30 MPa concrete.
Out of eight surfaces, one has satisfactory, three unsatisfactory, and four - poor performance.

Eastern Region: Five structures evaluated, all 30 MPa.
Out of five, one has satisfactory, two unsatisfactory, and two – poor performance.

Central Region: Two 30 MPa structures evaluated.
Out of two, one has unsatisfactory, and the other one - poor performance.

3.5.3 Long-term performance of concrete surface formed with and without liner

From data shown in Tab.7 and Tab.8, the summary of evaluation for the normal and the high performance concrete surfaces formed with and without the liner is compiled below:

Conventional concrete, 30 MPa							
Formed with liner				**Formed without liner**			
MTO Region	Number of barrier walls	Age of concrete (years)	Score	MTO Region	Number of barrier walls	Age of concrete (years)	Score
NW	8	10.3	6.0	NW	2	11	7.5
NE	7	8	6.7	NE	4	10	5.8
SW	6	11.5	6.5	SW	8	11.5	6
E	4	12.3	6.3	E	5	8.6	5.8
C	2	13	6.0	C	2	13	6.5
	Total number of barrier walls: 27	Average, 30MPa barrier walls: 11.0	Average, 30 MPa barrier walls: 6.3		Total number of barrier walls: 21	Average, 30MPa barrier walls: 10.8	Average, 30 MPa barrier walls: 6.3

High performance concrete, 50 MPa							
Formed with liner				**Formed without liner**			
MTO Region	Number of barrier walls	Age of concrete (years)	Score	MTO Region	Number of barrier walls	Age of concrete (years)	Score
NE	10	4.9	4.2	NE	3	3	4.3

The table shows data for the conventional and the high performance concrete for each of five Regions.

For the conventional concrete in walls formed with and without liners, having the total number of barrier walls evaluated (27 and 21) and the average age of concrete (11 and 10.8 years) statistically similar, it can be concluded that the same average scores (6.3 and 6.3) for walls formed with liner and without liner show that there is no improvement in long-term concrete durability.

The number of the HPC walls surveyed and the age of concrete are significantly lower than for the conventional concrete. One of the reasons is the introduction of the MTO HPC specifications in the 1998, only 6 years before the study started. Most of the MTO HPC structures were built in the Northastern Region; therefore all barrier walls surveyed are shown as one group. As the same time, only a few of those barrier walls were cast with the control sections, formed without the liner; therefore there is a disproportion between the number of walls formed with and without the liner. The score for hpc walls

formed with and without liner is similar (4.2 and 4.3), and lower than for the conventional concrete. The difference in age of both concretes (11 versus 4 years) has to be considered as a factor influencing the scores. However, it is safe to conclude that at the age of approximately 4 years, there is no improvement in the quality and durability of the HPC surfaces formed with and without the liner.

Overall, as shown in the table below, when comparing the barrier walls formed with and without the liner, the final results of the evaluation can be summarized as follows:

- 30 percent of all barrier walls formed with the liner had acceptable performance, as compared with 21 percent without liner.
- 70 percent of all barrier walls formed with the liner had unacceptable performance as compared with 79 percent without liner.

	Long-term performance of concrete surface			
	Acceptable		Unacceptable	
	Good	Satisfactory	Unsatisfactory	Poor
	Percent of evaluated structures			
Formed with liner	30		70	
n=37	14	16	42	28
Formed without liner	21		79	
n=24	8.5	12.5	33	46

4. NON-DESTRUCTIVE TESTING OF SURFACES FORMED USING LINERS

4.1 TESTING OF THE QUALITY OF CONCRETE SURFACE FORMED USING LINERS – REVIEW OF LITERATURE

Literature sources report the results of laboratory testing of concrete specimens cast with and without the use of liners[2, 4, 5, 6, 8, 12]. A limited amount of field testing of large size specimens or structure components are reported in [1, 8].

The final properties of the liner-formed concrete surface are greatly influenced by the amount of water and air filtered through the liner, and those in turn depend on mix properties (mainly w/c ratio) as well as the specimen size and geometry, casting position, and parameters of vibration.

4.2 FIELD TESTING OF THE EFFECTIVENESS OF FORM LINERS

While it is possible to fabricate test specimens with high quality of the concrete surface formed with the liner, it may be a challenge to duplicate the same quality under the average field conditions. Therefore, the actual effectiveness of form liners can only be comparatively assessed by non-destructive testing of full size 'as constructed' concrete surfaces formed with and without liner.

4.2.1 Evaluation criteria and test sites

The use of form liners for the placement of bridge deck barrier walls was specified on a trial basis on selected MTO construction contracts in all five regions. The special provisions for the trials specified use of the liner on the inside faces of the panels with the exception of two end (wingwall) panels, to be formed in a conventional manner, without the liner. Thus, the end panels could be used as control in field evaluation. After the initial trials were complete, liners were sometimes specified by individual region for the entire internal surface of the barrier walls.

To evaluate the liner effectiveness for 30 MPa and 50 MPa concrete, structures in similar environments and of similar age were selected for testing. After reviewing the above criteria for all 46 structures, a decision was made to carry out testing on three structures, all within an 80 km distance on Hwy 11, south of North Bay. The structures, constructed within a three-year period, from 2000 to 2003 were: Hwy 522 U-pass bridge, Goreville Road U-pass bridge and Big East River Service Road bridge.

4.2.2 Non-destructive tests

Surface hardness using the rebound hammer : Since the increase in the proportion of cement to fine aggregate due to the removal of water and air at the surface results in a denser and harder concrete surface, the rebound hammer readings for the liner-formed surface would be expected to be higher than for the surface formed without the liner.

The CT-320 Concrete Test Hammer (Soiltest Inc.) [13] was used, and the rebound numbers were recorded (Fig.26). Fifteen readings were taken approximately 10 cm apart and along two vertical paths on the liner-formed surface, and then on the conventionally formed surface. For an approximate evaluation of the compressive strength, the rebound numbers were then converted into cylinder compressive strength using conversion graphs.

Permeability to air using the TORRENT Permeability Tester [14] : As a results of liner use, a reduction of voids and pores in the surface zone was anticipated. Thus, air permeability of the liner formed surface should be lower than that of conventionally formed surface. The rate of pressure increase of in the vacuum cell of the TORRENT Permeability Tester applied to the concrete surface (Fig.27 and Fig.28) was monitored and the permeability coefficient kT, and the depth of vacuum penetration L, was calculated based on a theoretical model. Under field conditions, concrete moisture content correction was necessary, however, since the adjacent concrete surfaces of the same structure were tested within minutes from each other, the moisture correction could be ignored.

Electrical resistivity using the Wenner probe [15]: Generally, the resistivity of a porous material decreases with the increase of moisture content. Densified concrete at the surface with reduced pore system can hold less moisture and will restrict chloride ion infiltration. The electrical resistivity of the liner-formed surface should be higher than for the surface formed without the liner.

The Wenner resistivity probe has four equally spaced electrodes (Fig.29). A small AC current passes between the two outer electrodes. The resultant potential difference between the inner two electrodes is measured and the resistivity is calculated. The probe used in this study measures the proportion of the actual AC current flow to the nominal value of AC current flow, in percent. The accuracy of the measurement diminishes with decreasing amount of current passing between the outer electrodes.

Surface moisture content using high frequency capacitance moisture tester: For the same reasons that are valid for electrical resistivity, the moisture content measured at the surface formed with the liner should be lower than for the surface formed without the liner.
The HI-500 Concrete and Moisture Tester [16] is a high frequency capacitance moisture tester which measures the dielectric constant of concrete (Fig.30). The dielectric constant of concrete varies depending on the amount of moisture content in concrete. When calibrated, this constant is converted into a concrete moisture content value. However, for the purpose of this study, relative moisture content was measured using a generic scale of 0 to 1999 points.

4.2.3 Test results and analysis

Surface hardness/compressive strength: As shown in Table 8, there is no significant difference between the average rebound number for surfaces with and without liner tested for two 50 MPa, 48 versus 47, and 48 versus 49, respectively. The average rebound numbers for 30 MPa are 39 with liner, and 38 without liner. Although the rebound hammer test is considered a very approximate test for the compressive strength, the results show a good differentiation between the compressive strength of the 50 MPa concrete - average strength of 50.6 MPa and 51.5 MPa with liner, and 48.9 to 53.2 MPa without liner, and of the 30 MPa concrete - average strength of 34.7 MPa with liner and 34.4 MPa without liner.

Permeability to air: Two parameters describing the concrete permeability to air as tested using the Torrent tester were obtained, the permeability coefficient (kT), and the depth of vacuum penetration (L), into the concrete surface. The quality classes of cover concrete as determined by the kT (10^{-16} m^2) value are:

kT >10	very bad
10>kT> 1.0	bad
1.0>kT> 0.1	normal
0.1>kT> 0.01	good
0.01>kT	very good.

The average permeability coefficients for two hpc barrier walls are similar for surfaces with and without liner. For two tested 50 MPa concretes they are: 0.048×10^{-16} m^2 with liner versus 0.052×10^{-16} m^2 without liner, and 0.051×10^{-16} m^2 with liner versus 0.083×10^{-16} m^2 without liner.
There is an improvement from a 'normal' to a 'good' quality class for the 30 MPa concrete, the average kT for the surface with liner is 0.081×10^{-16} m^2, increasing to $kT = 0.211 \times 10^{-16}$ m^2 for concrete surface without liner.

Electrical resistivity: Because of a low moisture content (the average percentage of the nominal AC current flow between the electrodes of the probe was in the range of 33 to 36% for the 50 MPa concrete, and 57 to 62 % for the 30 MPa concrete), the resistivity results obtained for test and control surfaces are not the accurate resistivity values. However, since the surfaces with and without the liner have comparable levels of the percent nominal AC current flow, the relative resisitivity values can still be compared. As shown in Table 10, average electrical resistivities are similar for two 50 MPa concretes, 106 kOhm.cm (with liner) versus 103 (without liner), and 105 kOhm.cm (with liner) versus 111 (without liner), and so are the average resitivities for the 30 MPa concrete 14 kOhm.cm (with liner) versus 15 kOhm.cm (without liner).

Surface moisture content: Average relative moisture contents are very close (536.2 points with liner versus 540.3 points without liner), or the same (538.2 points with liner versus 538.2 points without liner) for the two tested 50 MPa concretes, respectively. The 30 MPa concrete surfaces tested at 507.4 points with liner and 484.5 points without liner. There is no significant difference in the relative moisture content for any of the surfaces formed with the liner as compared with the surface formed without the liner.

It can be concluded that the only measurable differences in quality of surfaces formed with and without the liner were tested for the 30 MPa concrete using the Torrent Air Permeability Tester. Overall, the quality improvement of surfaces formed with liner, as compared with the surfaces formed without liner were so small that only one test method had adequate sensitivity to detect any change.

5. SUMMARY AND CONCLUSIONS

To evaluate the effectiveness of form liners in improving the durability of concrete, the barrier walls of 46 bridge structures located in all five MTO Regions were assessed visually and tested non-destructively. This comprehensive study of the field performance of concrete formed with, as compared to formed without, the use of liners covers five different liners, two types of concrete (conventional, 30 MPa and high performance, 50 MPa), and structures constructed under MTO Contracts between 1992 and 2004.

Three surface conditions have been visually assessed as defining the long-term performance of concrete: open voids, discoloration and scaling. Other, non-rated conditions having lesser effect on the long-term performance, such as craze cracking, subsurface voids, and wrinkles/liner folds (due to improper installation of the liner) are also described and discussed.

The properties of the concrete surface layer such as hardness, air permeability, electrical resistivity and moisture content have been tested non-destructively for adjacent surfaces formed with and without use of the liner.

Based on visual evaluation of 37 barrier wall surfaces formed with liners as compared with 24 barrier wall surfaces formed without liner, it can be concluded that there is no evidence of the improvement in the long-term concrete durability that is significant enough to justify specification of the use of form liners as the concrete durability enhancement method.

Out of four non-destructive tests methods used, only one could detect any changes in the quality of the concrete surface, formed with the liner versus formed without the liner (the Torrent air permeability test). The test method is not standardized and its accuracy and precision are unknown, therefore it is not possible to establish if the difference between the results obtained is significant.

Finally, it has to be emphasized that the use of form liners cannot be considered a 'cure-all' to the problems resulting from concrete mix properties or construction practices. The use of form liner cannot disguise such problems as substandard mix quality or poor concrete placement or compaction practices.

6. REFERENCES

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Table 1. Northwestern Region sites

Sites with bridge barrier walls cast <u>WITH</u> form liner

Structure No.	HIGHWAY	LOCATION	YEAR CONSTRUCTED	MTO SITE No.	CONCRETE TYPE C (30 MPa) or HPC (50 MPa)	FORM LINER TYPE AND COVERAGE F(full) or P(partial)
1	2	3	4	5	6	7
1	17	Baldhead River East Branch	1997	38C-11	C	L1 - F
2	17	Bertrand Creek	1993	48C-31	C	L1 - F
3	17	Cypress River	1995	48C-16	C	L1 - F
4	17	Jackpine River	1996	48C-15	C	L1 - F
5	17	Little Gravel River	1995	48C-17	C	L1 - F
6	17	Michicopiten River	1997	38C-8	C	L3 - F
7	61	Slate River	1992	48W-70	C	L1 - F
8	17	Wabicoba Creek	1993	48E-29	C	L1 - F

Sites with bridge barrier walls cast <u>WITHOUT</u> form liner

Structure No.	HIGHWAY	LOCATION	YEAR CONSTRUCTED	MTO SITE No.	CONCRETE TYPE C (30 MPa) or HPC (50 MPa)	FORM LINER TYPE AND COVERAGE F(full) or P(partial)
1	2	3	4	5	6	7
9	17	West White River	1995	48E-32	C	None
10	17	White Lake Narrows	1993	48E-30	C	None

Table 2. Northeastern region sites
Structures with bridge barrier walls cast WITH form liner

Structure No.	HIGHWAY	LOCATION	YEAR CONSTRUCTED	MTO SITE No.	CONCRETE TYPE C (30 MPa) or HPC (50 MPa)	FORM LINER TYPE AND COVERAGE F(full) or P(partial)
1	2	3	4	5	6	7
11	11	Mattagami River	1993	39E-0002	C	L1 - P
12	11	Wellington Creek	1997	39W-0094	C	L1 – P
13	11	Lost River	2000	39W-0064	HPC	L4- F
14	101	Porcupine Creek (S. Porcupine)	1992	38E-0125	C	L1 - P
15	101	Porcupine River (Porcupine)	2000	39E-0083	HPC	L4-F(sealer)
16	101	North Driftwood Creek	1999	39E-0131	C	L1-F
17	11	McGilvray Creek	1995	44-0385	C	L1-F
18	11	Hwy 522 U-pass	2001	44-0371	HPC	L2-P
19	11	Goreville Rd. U-pass	2003	43-0376	HPC	L2-P
20	11	S.Muskoka Rd.Hwy588 Upass	2002	42-0079	C	L4- F
21	11	Big East River Service Rd.	2000	42-0316	C	L2-F
22	69/400	Airport Rd. U-pass	2002	44-0382	HPC	L1-F
23	69/400	Blackstone Crane L.Rd. U-pass	2002	44-0383	HPC	L2-F
24	69/400	Rankin Lake Rd. U-pass	2001	44-384	HPC	L2-F
25	69/400	Seguin Trail U-pass	2001	44-385	HPC	L2-F
26	69/400	Black Rd. U-pass	2001	44-401	HPC	L2-F
27	69/400	Badger Rd. U-pass	2001	44-386	HPC	L1 -F

Sites with bridge barrier walls cast WITHOUT form liner

Structure No.	HIGHWAY	LOCATION	YEAR CONSTRUCTED	MTO SITE No.	CONCRETE TYPE C (30 MPa) or HPC (50 MPa)	FORM LINER TYPE AND COVERAGE F(full) or P(partial)
1	2	3	4	5	6	7
28	101	Ivanhoe River	1992	46-0003	C	None
29	1101	Moose Creek	2004	39E-0084	HPC	None

Table 3. Southwestern Region sites

Sites with bridge barrier walls cast WITH form liner

Structure No.	HIGHWAY	LOCATION	YEAR CONSTRUCTED	MTO SITE No.	CONCRETE TYPE C (30 MPa) or HPC (50 MPa)	FORM LINER TYPE AND COVERAGE F(full) or P(partial)
1	2	3	4	5	6	7
30	401 EB	Flook and Hinton Drain	1994	13-0229	C	L1 - P
31	401 EB	Releigh Plains Drain	1994	13-0228	C	L1 - P
32	401 EB	McDougall Drain	1994	13-0190	C	L1 – P
33	401 EB	Little Baptist Creek	1994	13-0187	C	L1 – P
34	401 WB	Duck Creek	1992	06-0086	C	L1 – P
35	401 EB	Duck Creek	1993	06-0086	C	L1 - P

Sites with bridge barrier walls cast WITHOUT form liner

Structure No.	HIGHWAY	LOCATION	YEAR CONSTRUCTED	MTO SITE No.	CONCRETE TYPE C (30 MPa) or HPC (50 MPa)	FORM LINER TYPE AND COVERAGE F(full) or P(partial)
1	2	3	4	5	6	7
36	401 EB	Government Drain No.2	1994	13-0152	C	None
37	401 WB	Belle River	1993	06-0084	C	None

Table 4. Eastern Region sites

Sites with bridge barrier walls cast WITH form liner

Structure No.	HIGHWAY	LOCATION	YEAR CONSTRUCTED	MTO SITE No.	CONCRETE TYPE C (30 MPa) or HPC (50 MPa)	FORM LINER TYPE AND COVERAGE F(full) or P(partial)
1	2	3	4	5	6	7
38	401	Theatre Rd. O-pass	1993	21- 0242	C	L3 - F
39	401	Percy St. U-pass	1992	21-0276	C	L1 - F
40	416	Knoxdale Rd. U-pass	1993	3-0546	C	L1 - P
41	416	Log Farm Access U-pass	1993	3-0545	C	L1 – P(sealer)

Sites with bridge barrier walls cast WITHOUT form liner

Structure No.	HIGHWAY	LOCATION	YEAR CONSTRUCTED	MTO SITE No.	CONCRETE TYPE C (30 MPa) or HPC (50 MPa)	FORM LINER TYPE AND COVERAGE F(full) or P(partial)
1	2	3	4	5	6	7
42	401	Burnham Rd.U-pass	2002	21-0243	C	None
43	416	Dilworth Rd. U-pass	1997	03-0574	C	None
44	416	River Rd. U-pass	1997	16-0320	C	None

Table 5. Central Region sites

Sites with bridge barrier walls cast WITH form liner

Structure No.	HIGHWAY	LOCATION	YEAR CONSTRUCTED	MTO SITE No.	CONCRETE TYPE C (30 MPa) or HPC (50 MPa)	FORM LINER TYPE AND COVERAGE F(full) or P(partial)
1	2	3	4	5	6	7
45	169	Black River (Gregg Bridge)	1992	22-0004	C	L5 - P
46	60	Pine River (Angus)	1992	30-0203	C	L1 - P

Table 6. Visual evaluation of surface condition, surfaces formed WITH liner

					Rated surface conditions			
Region	Structure	Concrete	Liner	Age	Voids	Discolor	Scaling	Score
Northwestern	2	1	L1	12	1	2	2	5
	3	1	L1	10	3	3	2	8
	5	1	L1	10	3	5	5	13
	7	1	L1	13	2	3	1	6
	8	1	L1	12	1	2	2	5
	1	1	L3	8	1	1	1	3
	4	1	L3	9	2	2	1	5
	6	1	L3	8	1	1	1	3
Northeastern	11	1	L1	8	3	5	1	9
	12	1	L1	9	1	3	3	7
	14	1	L1	13	3	2	1	6
	16	1	L1	6	2	3	4	9
	17	1	L1	10	1	4	2	7
	20	1	L2	6	1	2	1	4
	22	2	L1	5	1	2	1	4
	18	2	L2	4	1	2	1	4
	19	2	L2	4	1	2	1	4
	23	2	L2	5	1	2	1	4
	24	2	L2	5	3	2	1	6
	25	2	L2	5	1	2	1	4
	26	2	L2	5	1	1	1	3
	27	2	L2	6	1	1	1	3
	13	2	L4	5	3	2	1	6
	15 */	2	L4	5	1	1	1	4*/
	21	1	L4	4	3	1	1	5
Southwestern	30	1	L1	11	2	4	1	7
	31	1	L1	11	2	3	2	7
	32	1	L1	11	2	3	2	7
	33	1	L1	11	2	3	1	6
	34	1	L1	13	2	3	1	6
	35	1	L1	12	2	3	1	6
Eastern	39	1	L1	13	2	2	2	6
	40	1	L1	12	2	2	2	6
	41 */	1	L1	12	2	1	1	5*/
	38	1	L3	12	4	2	1	7
Central	46	1	L1	13	3	5	1	9
	45	1	L5	13	1	1	1	3

Legend:

Structure: see Tab. 1 to 5 for structure details

Concrete: 1 - 30 MPa (conventional) 2 - 50 MPa (high performance)

*/ - sealer applied to concrete surface, score increased

Visual rating for surface condition (voids, discoloration, scaling):

1 point - light
2 points - mild
3 points - moderate
4 points - severe
5 points - very severe

Score/ performance:

3 points - good
4 points - satisfactory
5 and 6 points - unsatisfactory
7 points and up - poor

Table7. Visual evaluation of surface condition, surfaces formed WITHOUT liner

Region	Structure	Concrete	Liner	Age	Rated surface conditions			Score
					Voids	Discolor	Scaling	
NWR	9	1	0	10	1	1	5	7
	10	1	0	12	3	1	4	8
Northeastern	11	1	0	8	1	1	1	3
	12	1	0	9	2	1	4	7
	14	1	0	13	2	1	1	4
	28	1	0	10	3	1	5	9
	18	2	0	4	1	1	1	3
	19	2	0	4	3	1	1	5
	29	2	0	1	2	2	1	5
Southwestern	30	1	0	11	1	2	1	4
	31	1	0	11	3	1	3	7
	32	1	0	11	3	1	3	7
	33	1	0	11	3	1	1	5
	34	1	0	13	4	1	2	7
	35	1	0	12	4	1	1	6
	36	1	0	11	1	1	3	5
	37	1	0	12	5	1	1	7
Eastern	40	1	0	12	3	1	2	6
	41 */	1	0	12	5	1	1	8 */
	42	1	0	3	2	1	3	6
	43	1	0	8	3	2	2	7
	44	1	0	8	2	1	1	4
Central	45	1	0	13	3	1	3	7
	46	1	0	13	4	1	1	6

Legend:

Structure: see Tab. 1 to 5 for structure details

Concrete: 1 - 30 MPa (conventional) 2 - 50 MPa (high performance)

*/ - sealer applied to concrete surface, score increased

Visual rating for surface condition (voids, discoloration, scaling):

1 point - light
2 points - mild
3 point - moderate
4 points - severe
5 points - very severe

Score/ performance:

3 points - good
4 points - satisfactory
5-6 points - unsatisfactory
7 points and up - poor

Table 8. Comparative, non-destructive evaluation of surfaces formed WITH and WITHOUT the liner

TEST	HPC (1)		HPC (2)		CC	
	Liner (+)	Liner (-)	Liner (+)	Liner (-)	Liner (+)	Liner (-)
REBOUND HAMMER	n=15	n=15	n=15	n=15	n=15	n=15
Rebound number						
average	**48**	**47**	**48**	**49**	**39**	**38**
st.dev.	3	1	3	2	3	2
coeff. of variation(%)	6	3	7	5	9	6
Cylinder compressive strength (MPa)						
average	**50.6**	**48.9**	**51.5**	**53.2**	**34.7**	**34.4**
st.dev.	4.6	2.6	5.6	3.9	5.8	3.8
coeff. of variation(%)	9.2	5.3	10.8	7.3	16.7	11.1
TORRENT AIR PERMEABILITY	n=8	n=8	n=6	n=6	n=8	n=8
Permeability coefficient kT, ($10^{-16}m^2$)						
average	**0.048**	**0.052**	**0.051**	**0.083**	**0.081**	**0.211**
st.dev.	0.024	0.046	0.04	0.064	0.056	0.087
coeff. of variation(%)	50	87	79	76	70	41
Depth of vacuum penetration, L(mm)						
average	**14.1**	**14.2**	**14.3**	**17.9**	**16.6**	**30.6**
st.dev.	4.6	7.3	7.2	8.2	6.2	5.7
coeff. of variation(%)	32	52	50	46	37	19
WENNER RESISTIVITY	n=6	n=6	n=6	n=6	n=6	n=6
Resitivity (kOhm.cm)						
average	**106**	**103**	**105**	**111**	**14**	**15**
st.dev.	14	9	18	14	5	3
coeff. of variation(%)	13	9	17	12	37	23
@ percent nominal current flow (average)	**35**	**34**	**36**	**33**	**57**	**62**
CAPACITANCE MOISTURE PROBE	n=7	n=7	n=7	n=7	n=7	n=7
Relative moisture content (0-1999 point scale)						
average	**536.2**	**540.3**	**538.2**	**538.2**	**507.4**	**484.5**
st.dev.	10.1	18.5	15.1	12.9	14.2	26.1
coeff. of variation(%)	1.9	3.4	2.8	2.4	2.8	5.4

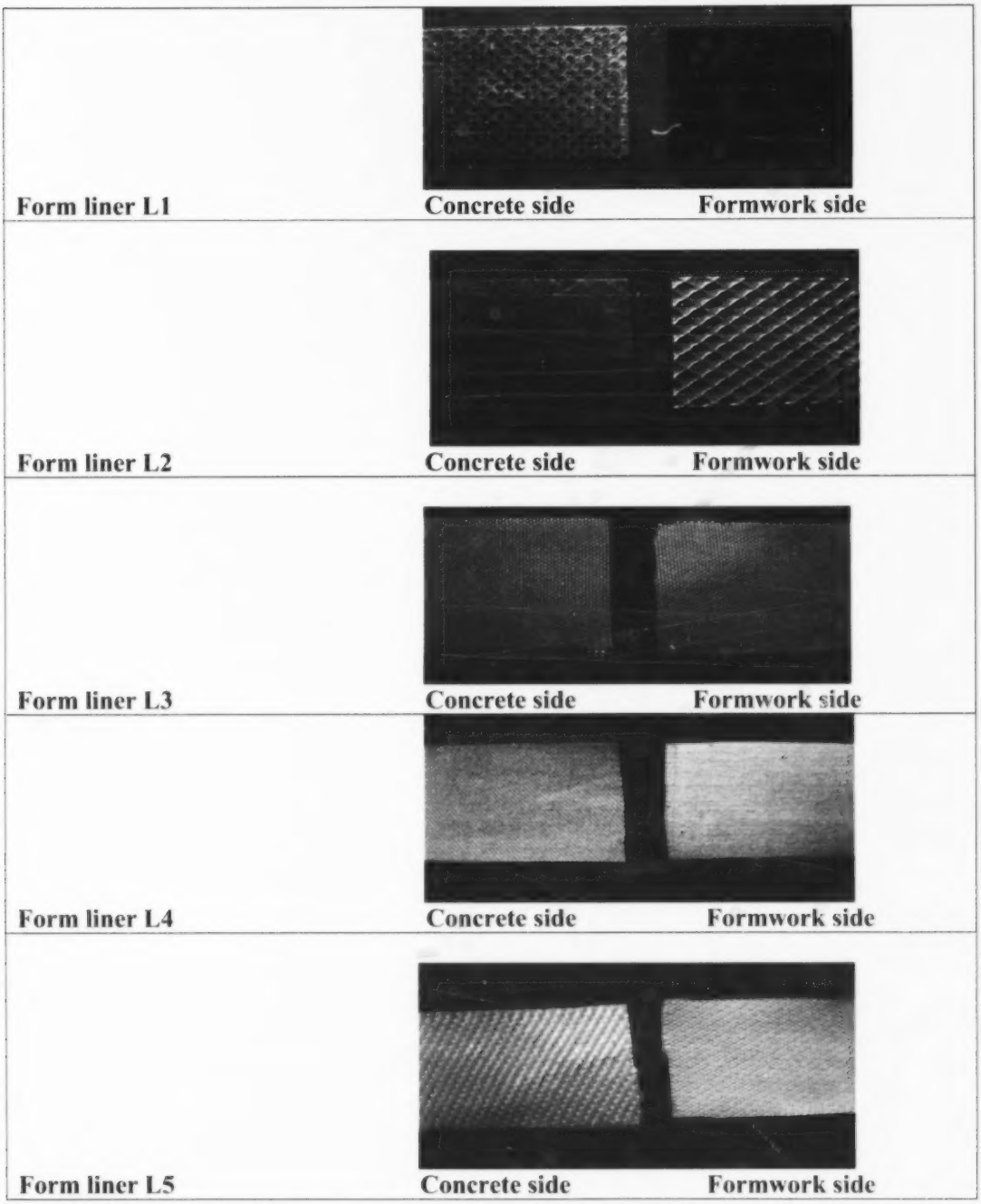

Fig. 1 Form liners used in 1992-2004 MTO Contracts

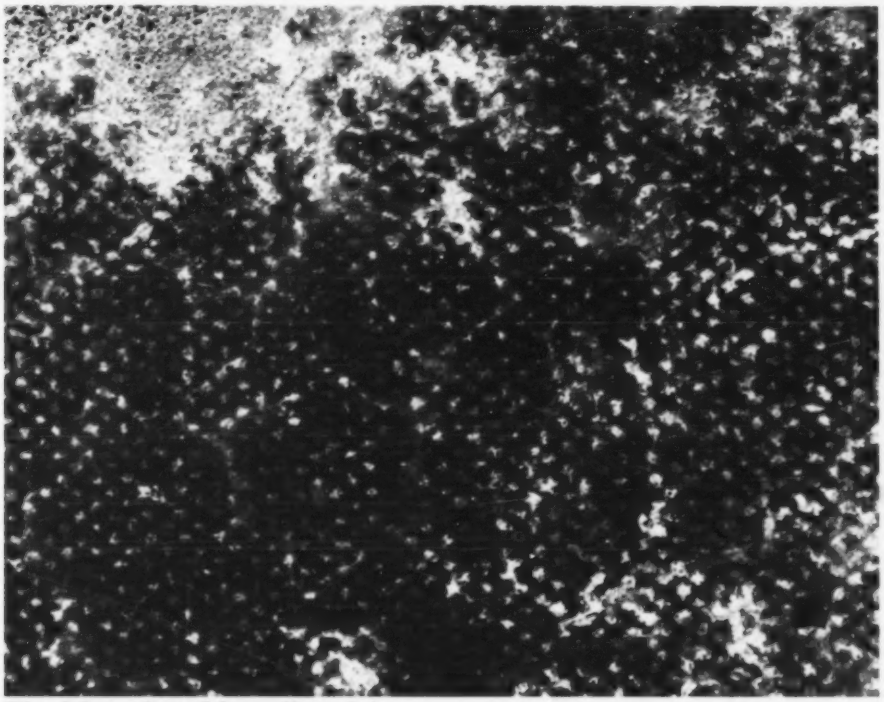

Fig. 2 Imprint of form liner L1

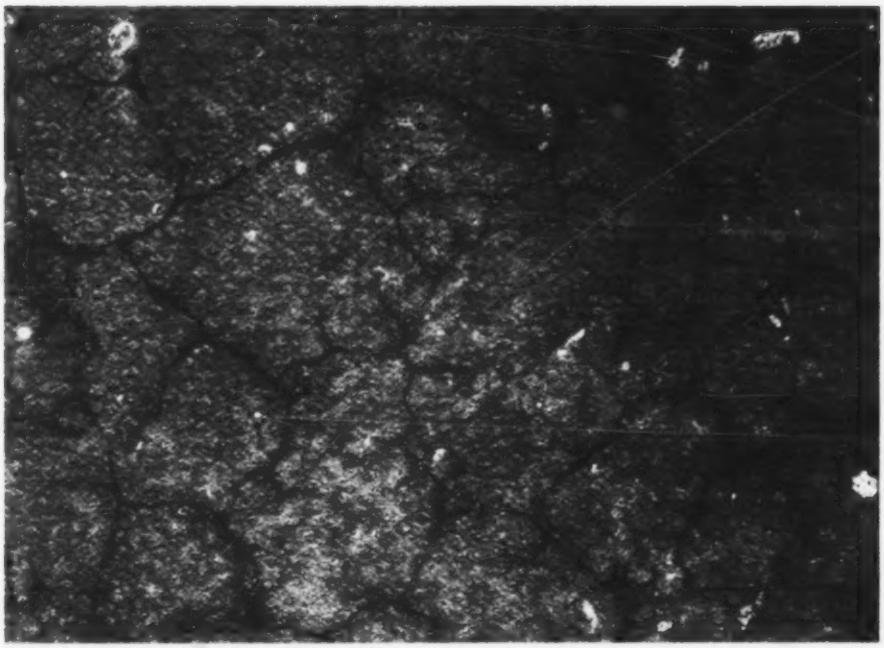

Fig. 3 Imprint of form liner L2

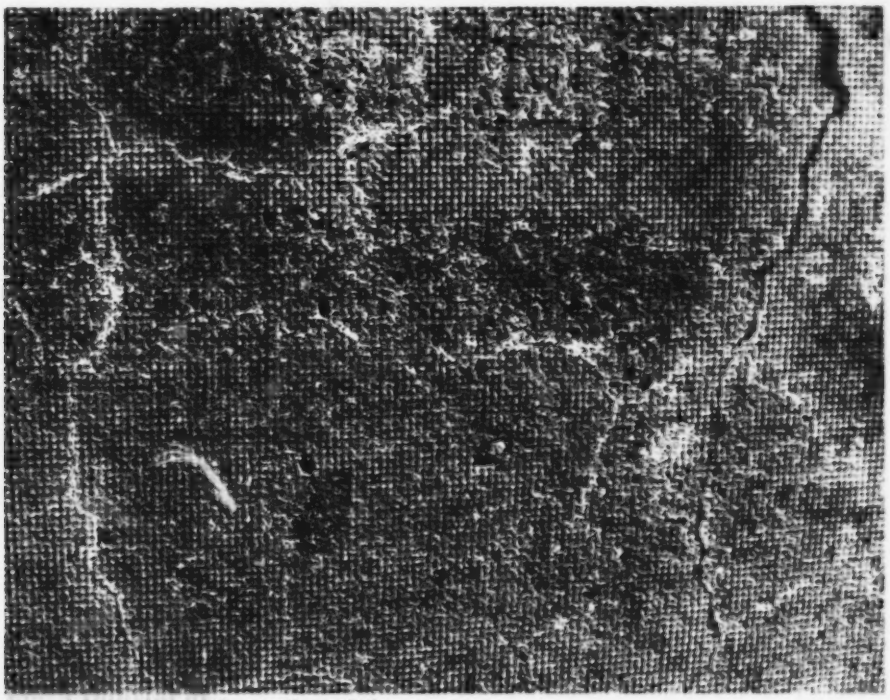

Fig. 4 Imprint of form liner L3

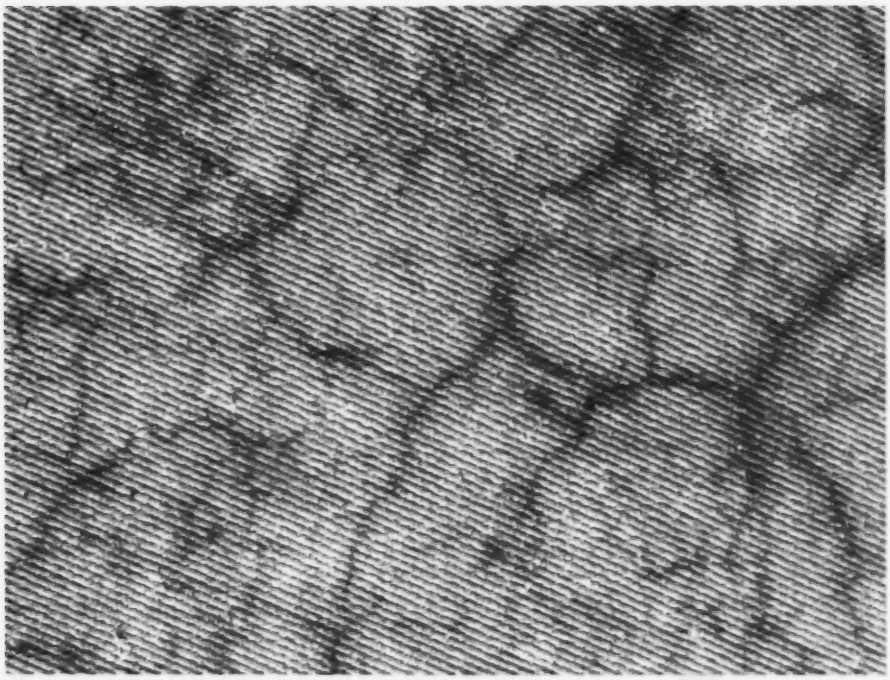

Fig.5 Imprint of form liner L4

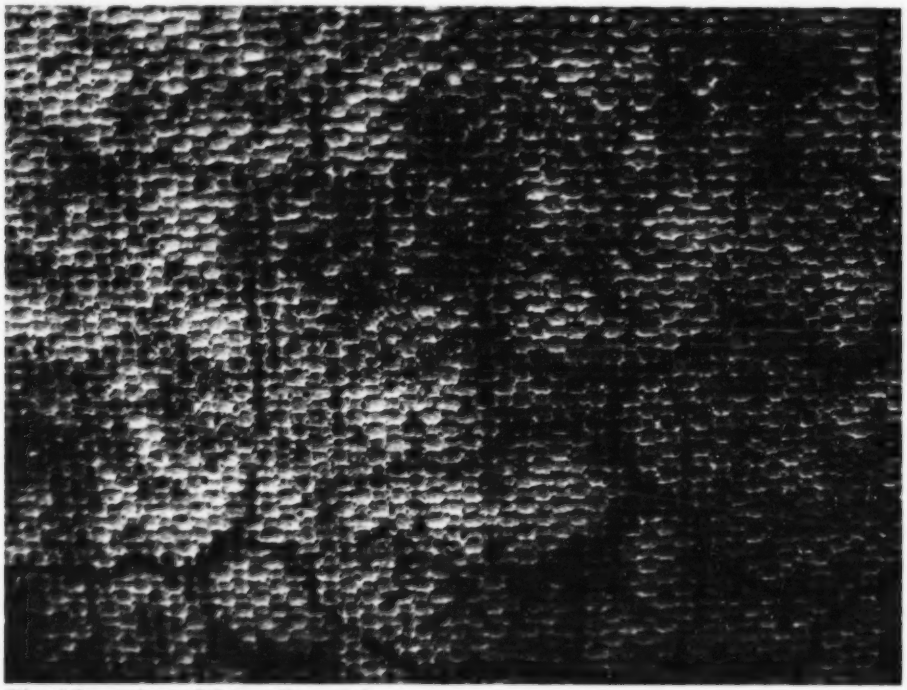

Fig.6 Imprint of form liner L5

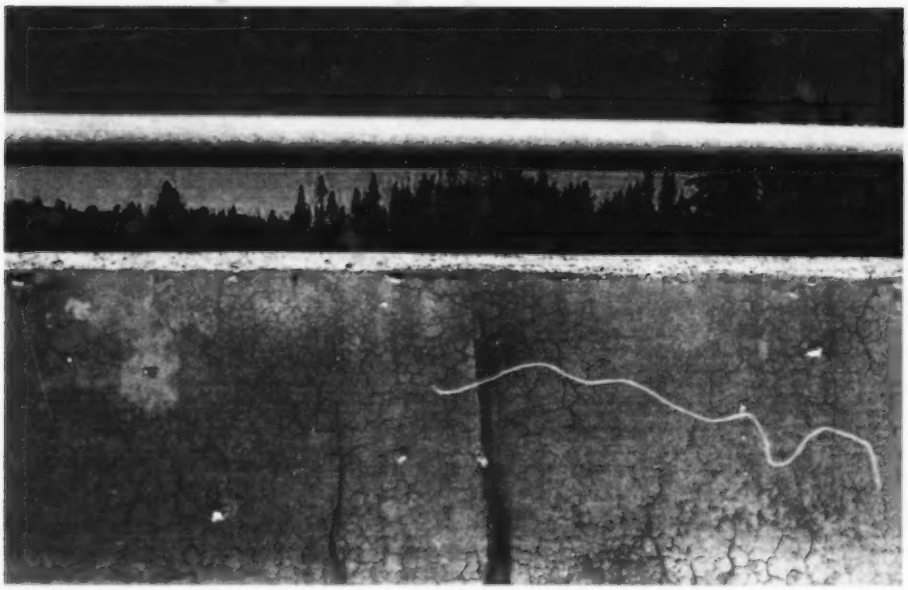

Fig.7 Open voids, visual rating 1 point (light)

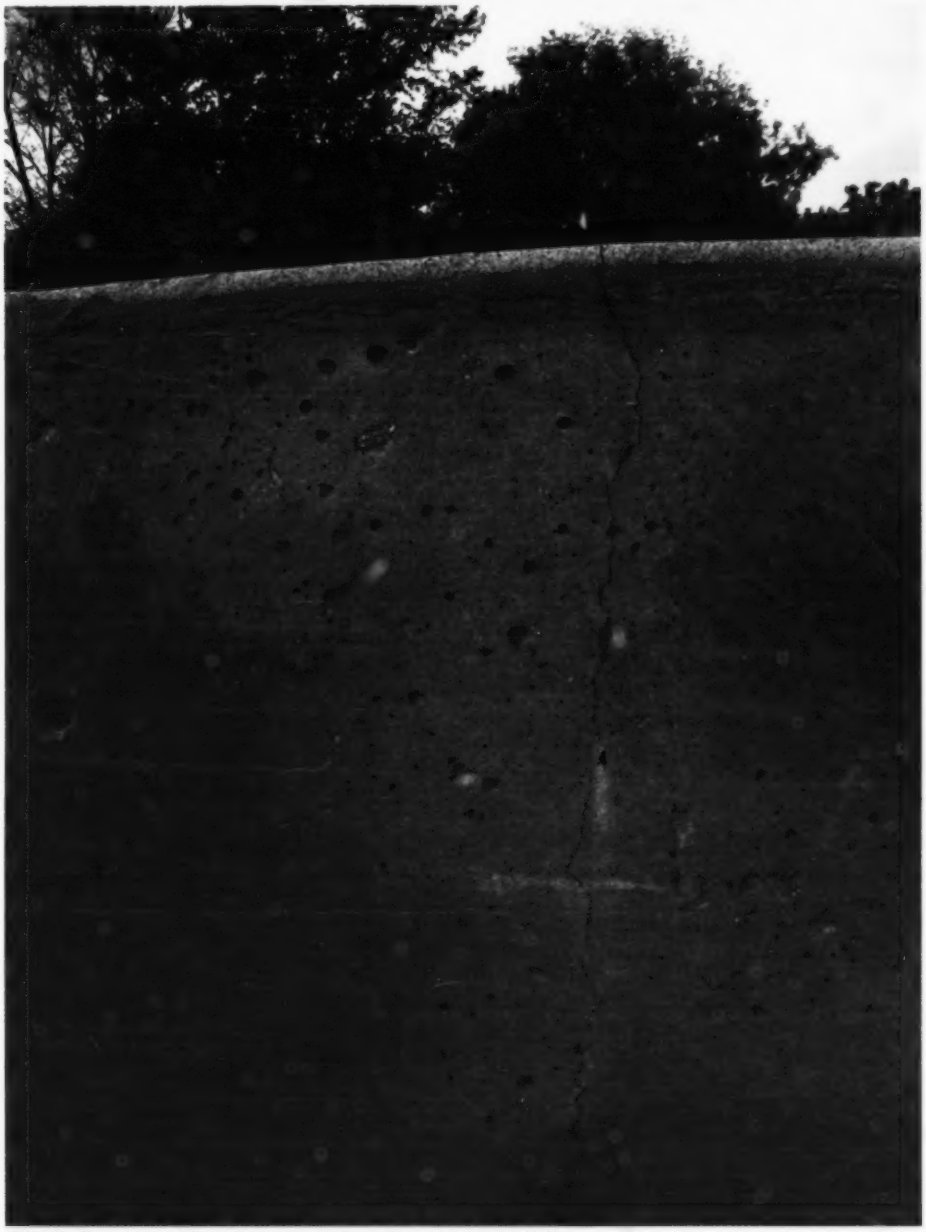

Fig.8 Open voids, visual rating 2 points (mild)

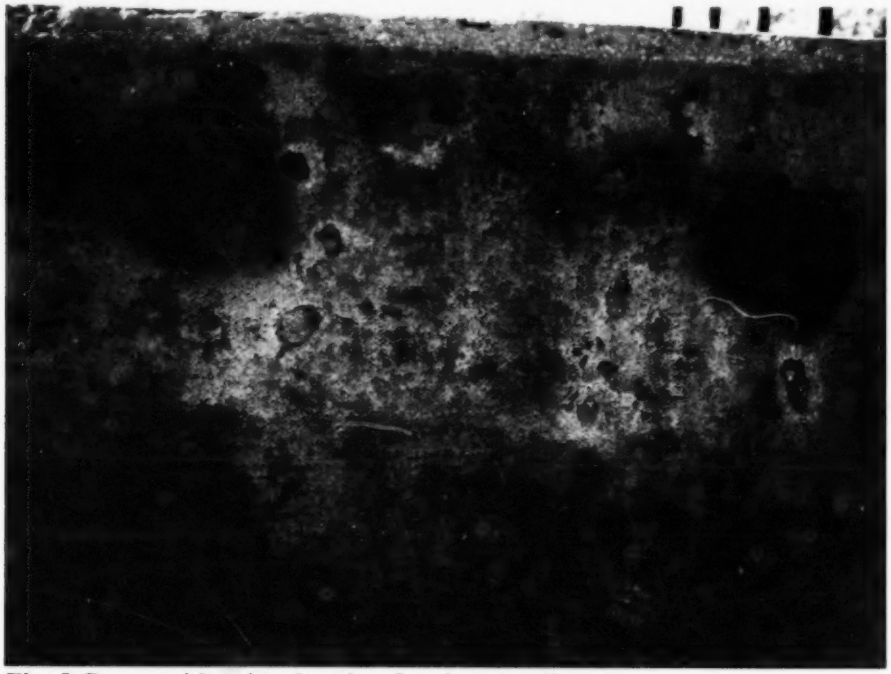

Fig. 9 Open voids, visual rating 3 points (moderate)

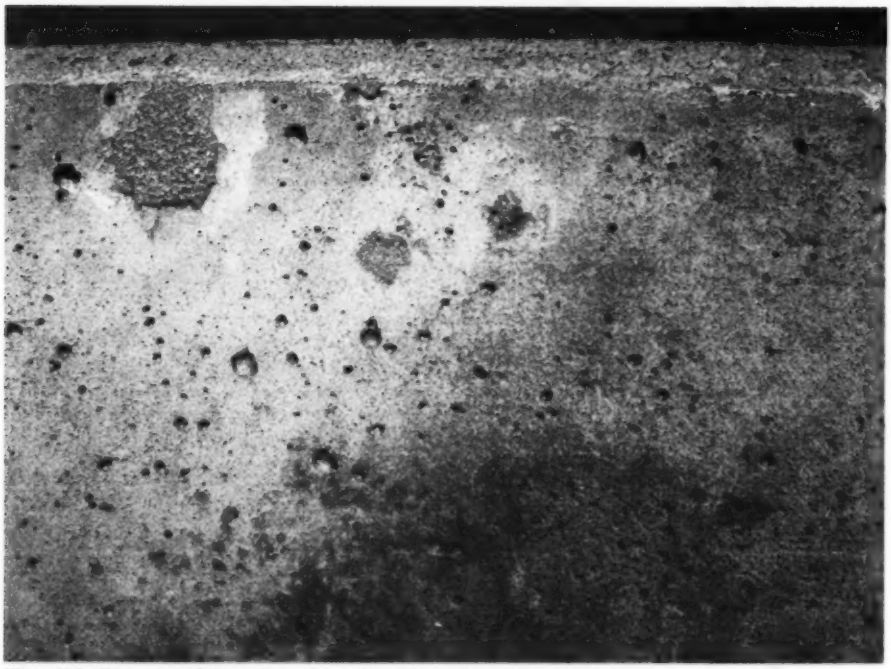

Fig. 10 Open voids, visual rating 4 points (severe)

Fig.11 Open voids, visual rating 5 points (very severe)

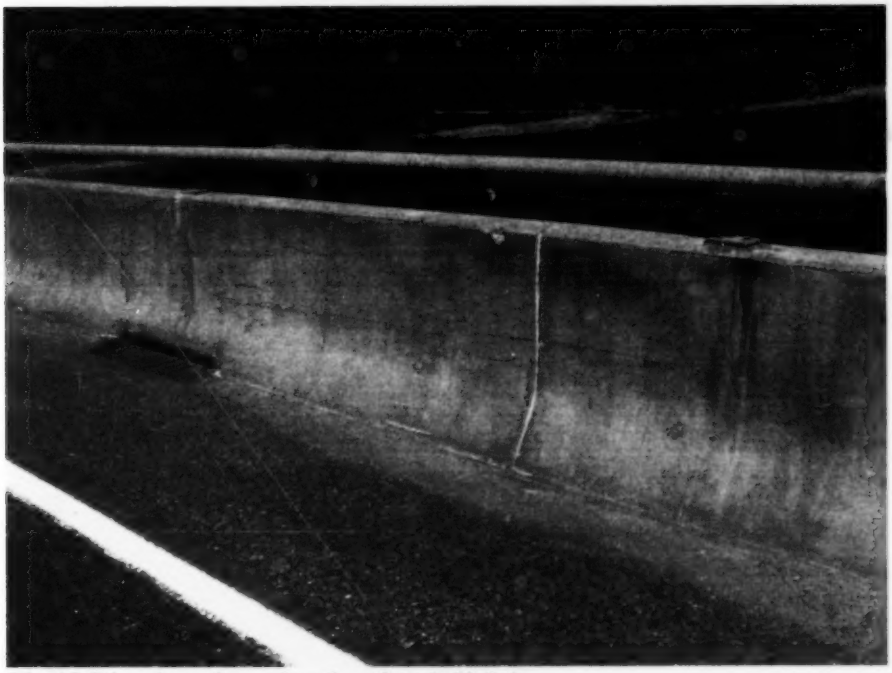

Fig.12 Discoloration, visual rating 1 (light)

Fig. 13 Discoloration, visual rating 2 points (mild)

Fig. 14 Discoloration, visual rating 3 points (moderate)

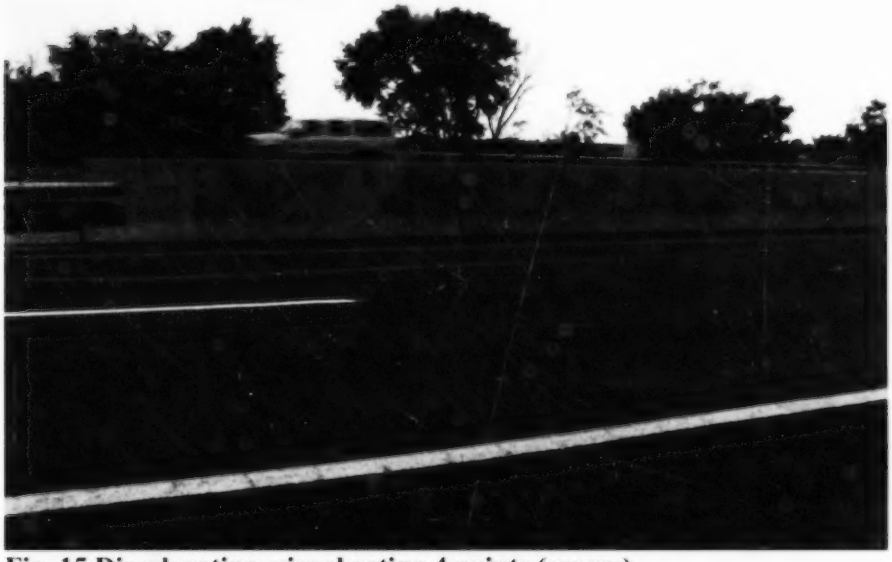

Fig. 15 Discoloration, visual rating 4 points (severe)

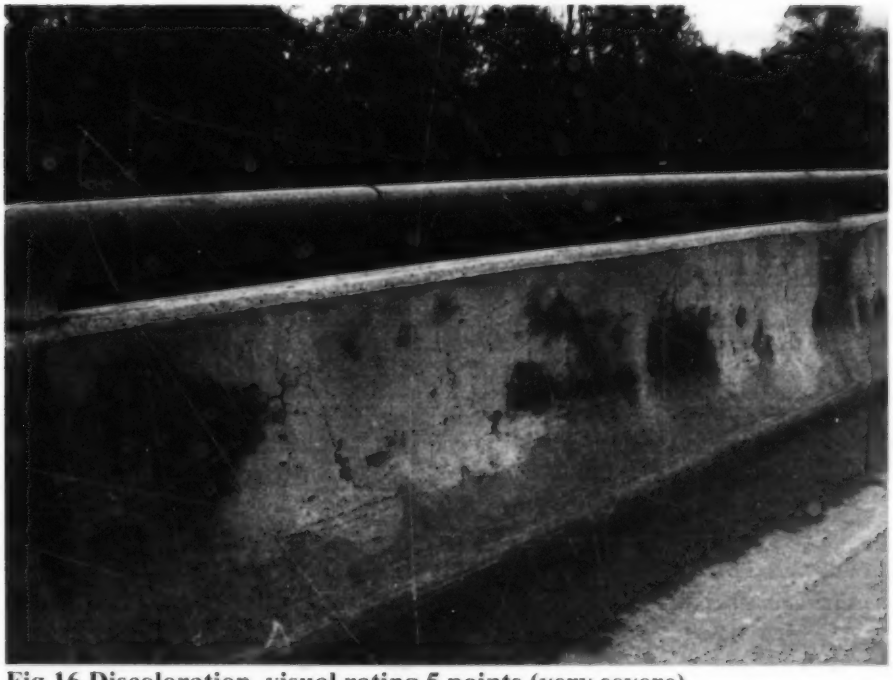

Fig.16 Discoloration, visual rating 5 points (very severe)

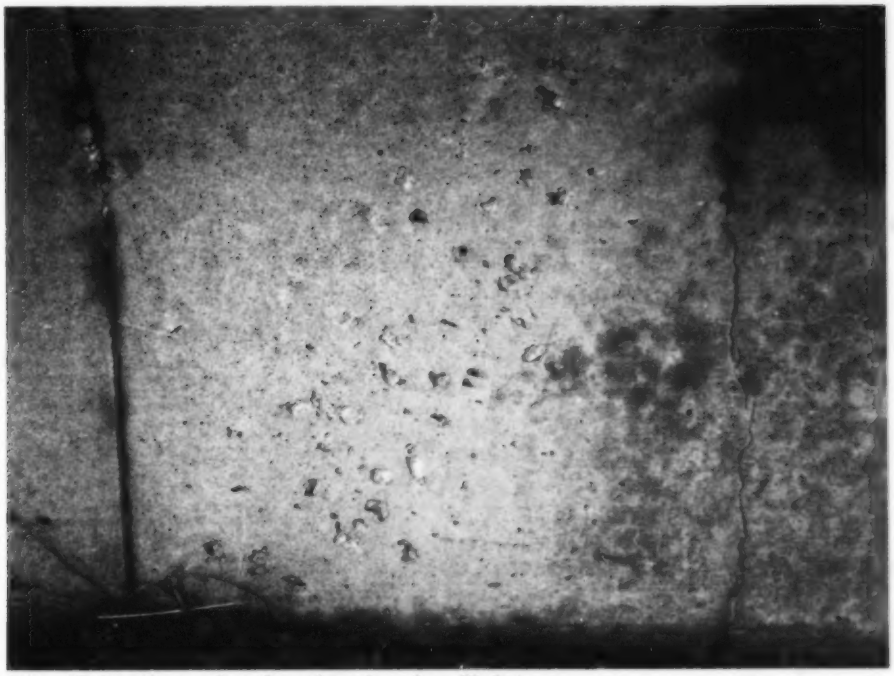

Fig. 17 Scaling, visual rating 1 point (light)

Fig. 18 Scaling, visual rating 2 points (mild)

Fig. 19 Scaling, visual rating 3 points (moderate)

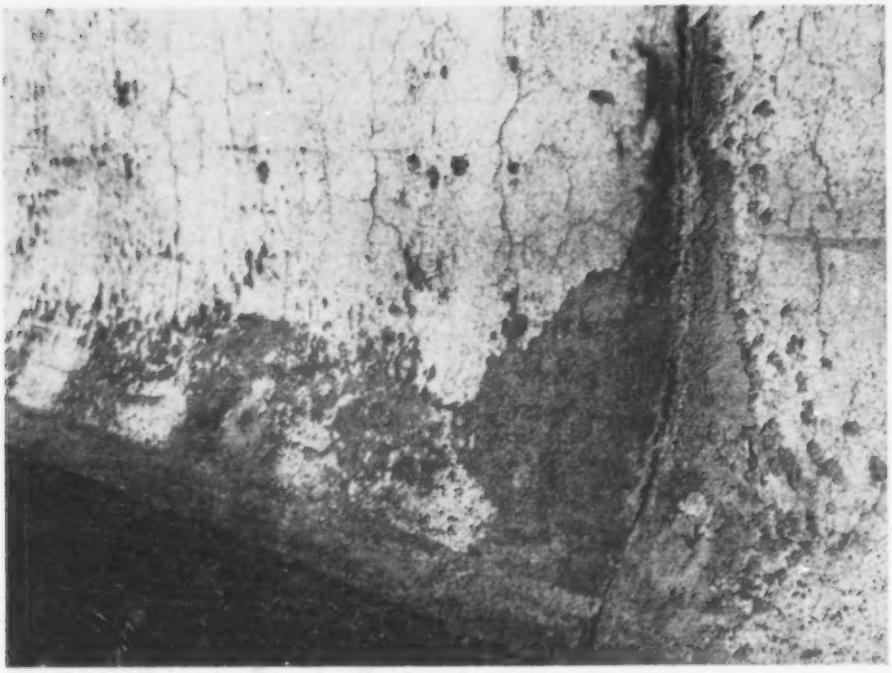

Fig. 20 Scaling, visual rating 4points (severe)

Fig. 21 Scaling, visual rating 5 points (very severe)

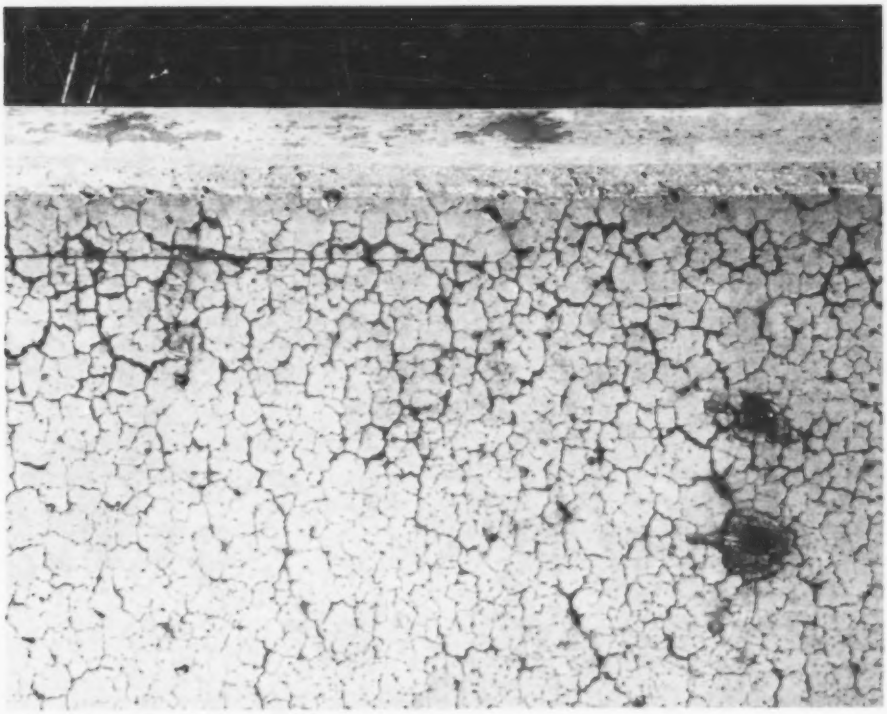

Fig. 22 Non-rated condition - crazing

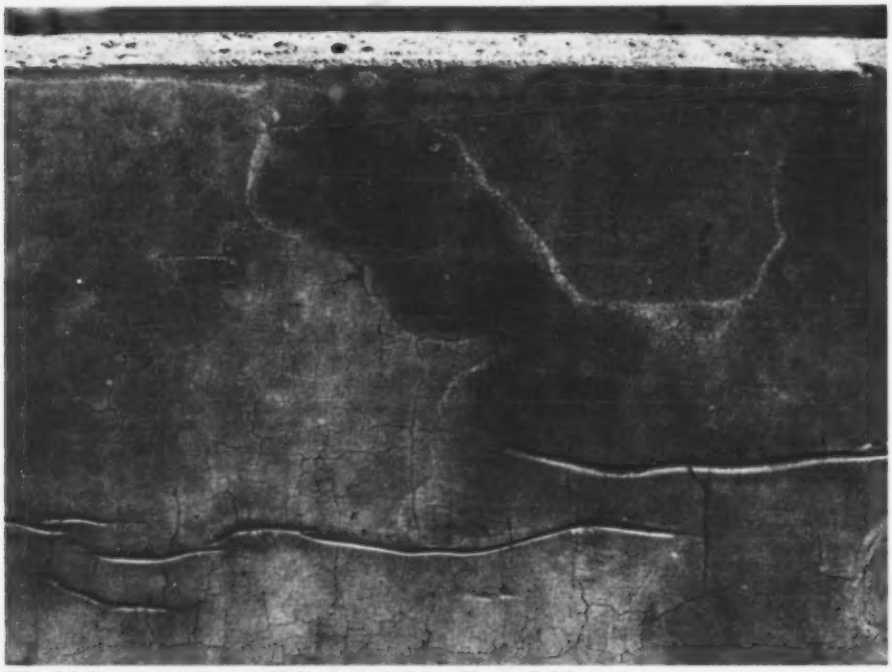

Fig.23 Non-rated condition, wrinkles/liner folds (A)

Fig. 24 Non-rated condition, wrinkles/liner folds (B)

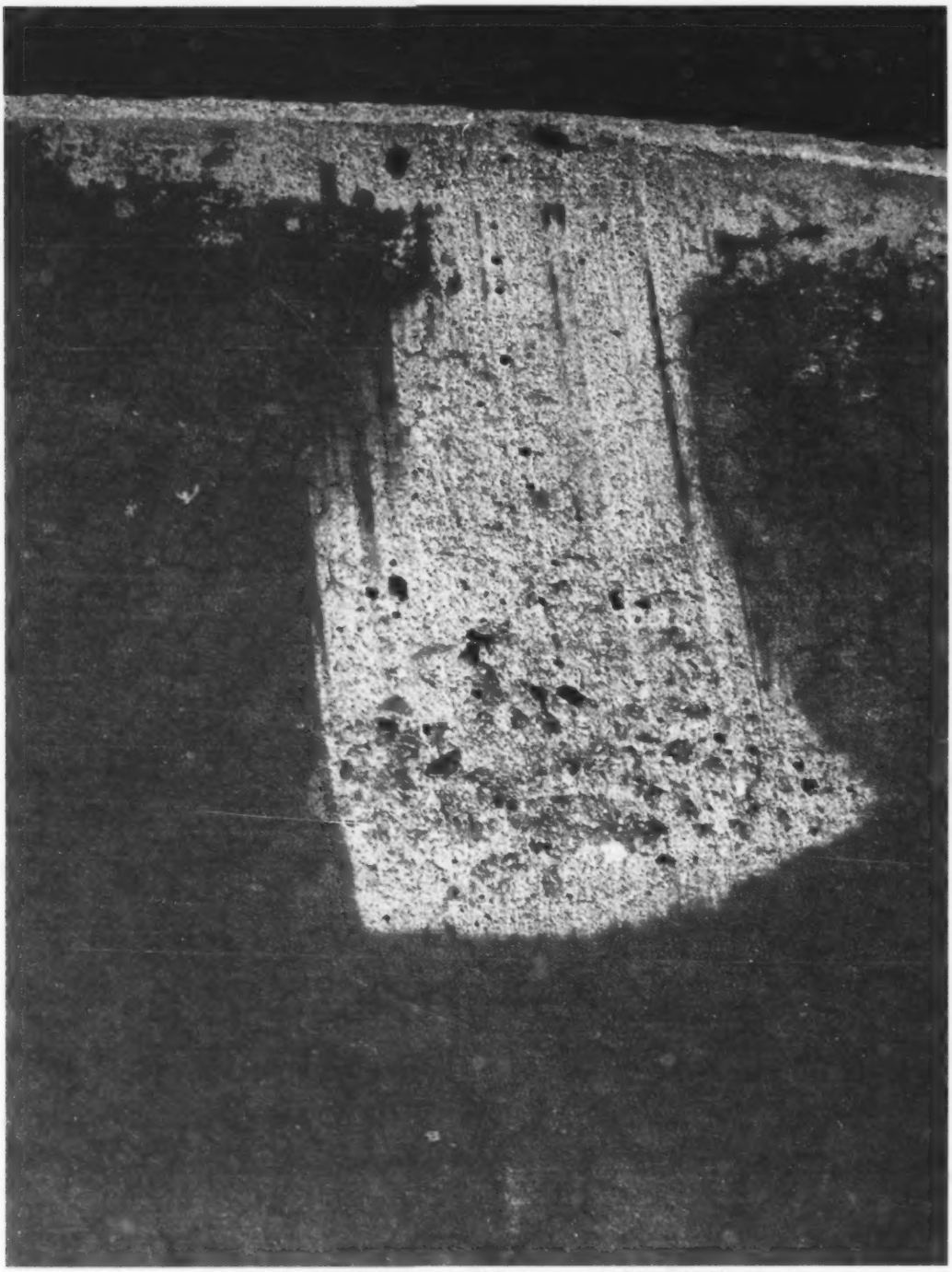

Fig. 25 Non-rated condition, subsurface voids (exposed by grinding)

Fig.26 Rebound hammer test

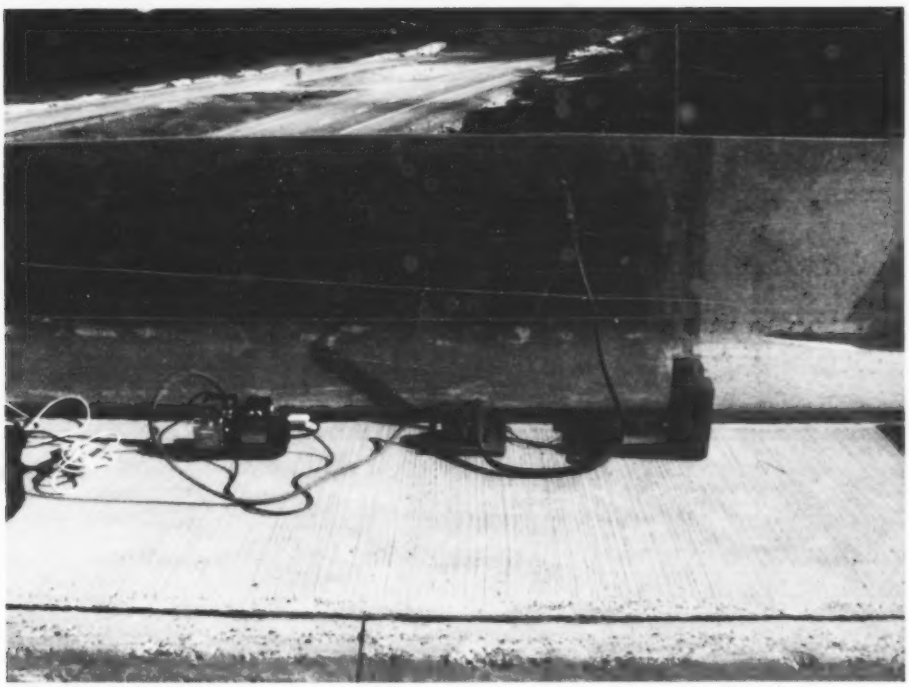

Fig.27 TORRENT air permeability test – surface formed with liner

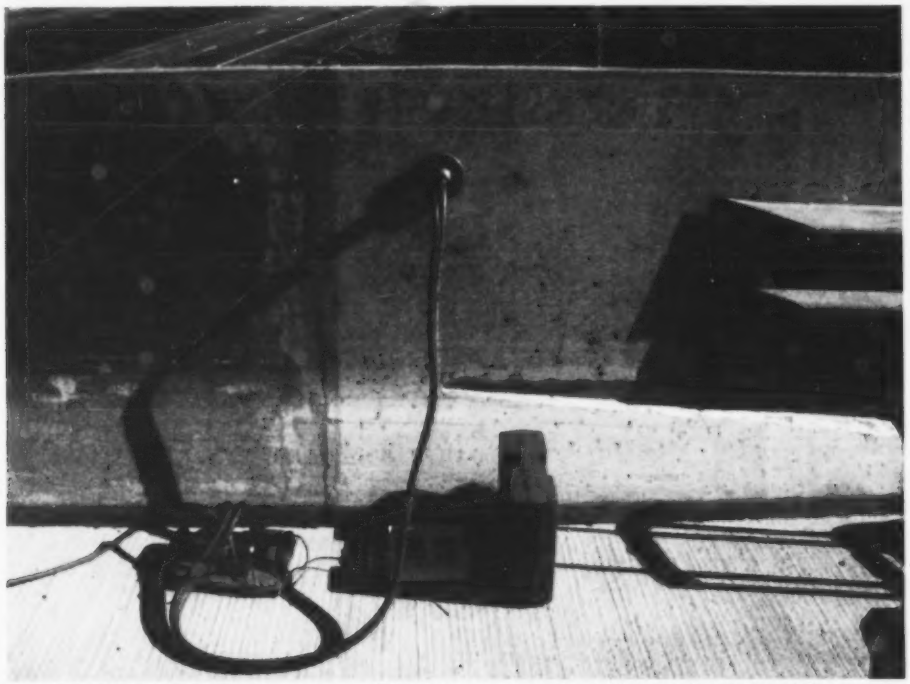

Fig.28 TORRENT air permeability test – surface formed without liner

Fig.29 Wenner resistivity test

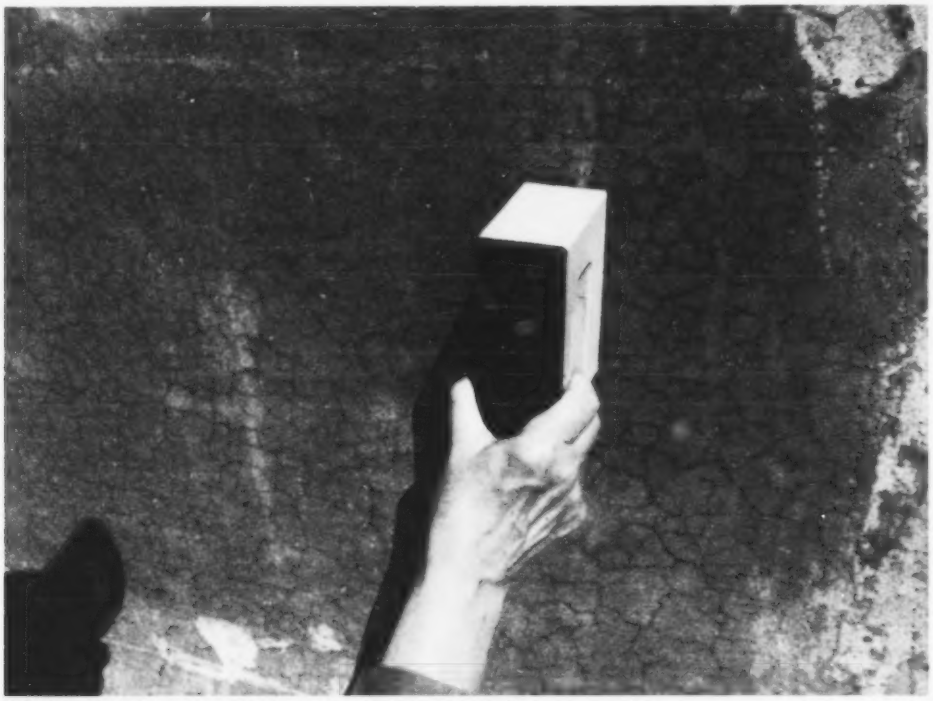

Fig.30 Moisture content test using capacitance probe